INITIATIVE ON
Asian Mega-Deltas

Enhancing Climate Resilience and Productivity in Mekong Deltas by Improving Rice-Field Pond

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CGIAR

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Asian Mega-Deltas

Contents

1. Introduction and Objective

Rice-field fisheries have long been a cornerstone of Cambodia's rural landscape, providing essential sustenance and income for millions. Recognizing their importance, the CGIAR Initiative on Asian Mega-Deltas (AMD) has led transformative experiments aimed at maximizing the potential of rice-field ponds to enhance rural livelihoods and promote sustainable development. Under AMD's Work Package 1 (WP1), which focuses on adapting deltaic production systems, the Initiative seeks to scale innovations that support resilient, diversified production systems while minimizing environmental impacts and mitigating climate risks. A key component of these efforts is the development of Community Fish Refuges (CFRs), which are crucial for protecting wild fish populations and creating abundant habitats for breeding and thriving.

In collaboration with stakeholders, the Fisheries Administration (FiA) has supported the establishment of 183 CFRs across the Mekong Delta in Cambodia (FiA, 2022), However many of them need to improve the management and system (VSSN, 2023). These fisheries have yielded substantial harvests, with finfish catches averaging 104 kg/ha annually and other aquatic animals contributing 34 kg/ha, serving as a notable source of food consumption for rural people (Freed et al, 2020). Rice-field ponds within rice fields, which are part of the rice-field fisheries system, serve a dual purpose: they act as vital fish refuge ponds in times of drought during the wet season, and they contribute to family income and fish consumption among owners after the rice harvest. However, the productivity of these ponds can vary because of factors such as their location and management practices. Rice-field ponds, frequently found near CFRs, are owned by 39% of households and typically measure an average size of 129 m². These ponds contribute to local livelihoods by providing an average annual fish catch of 46 kg (Nuppun, 2016). Some fish species, like snakehead, catfish, and climbing perch, are stocked for breeding and are returned to the rice-field pond, where they are recaptured during the dry season, in March or April.

These fields are vital for inland fish production and contribute to rural livelihoods, food security, and income generation. With this in mind, an experiment was conducted with the following three objectives:

1. Evaluate the fish yield and income earned by rural communities.
2. Introduce and demonstrate climate-adaptive technologies to increase the productivity of fisheries and rice yields.
3. Assess the survival rate and weight gain of fish stocked in rice-field ponds during the dry season.

2. Experimental Design and Methodologies

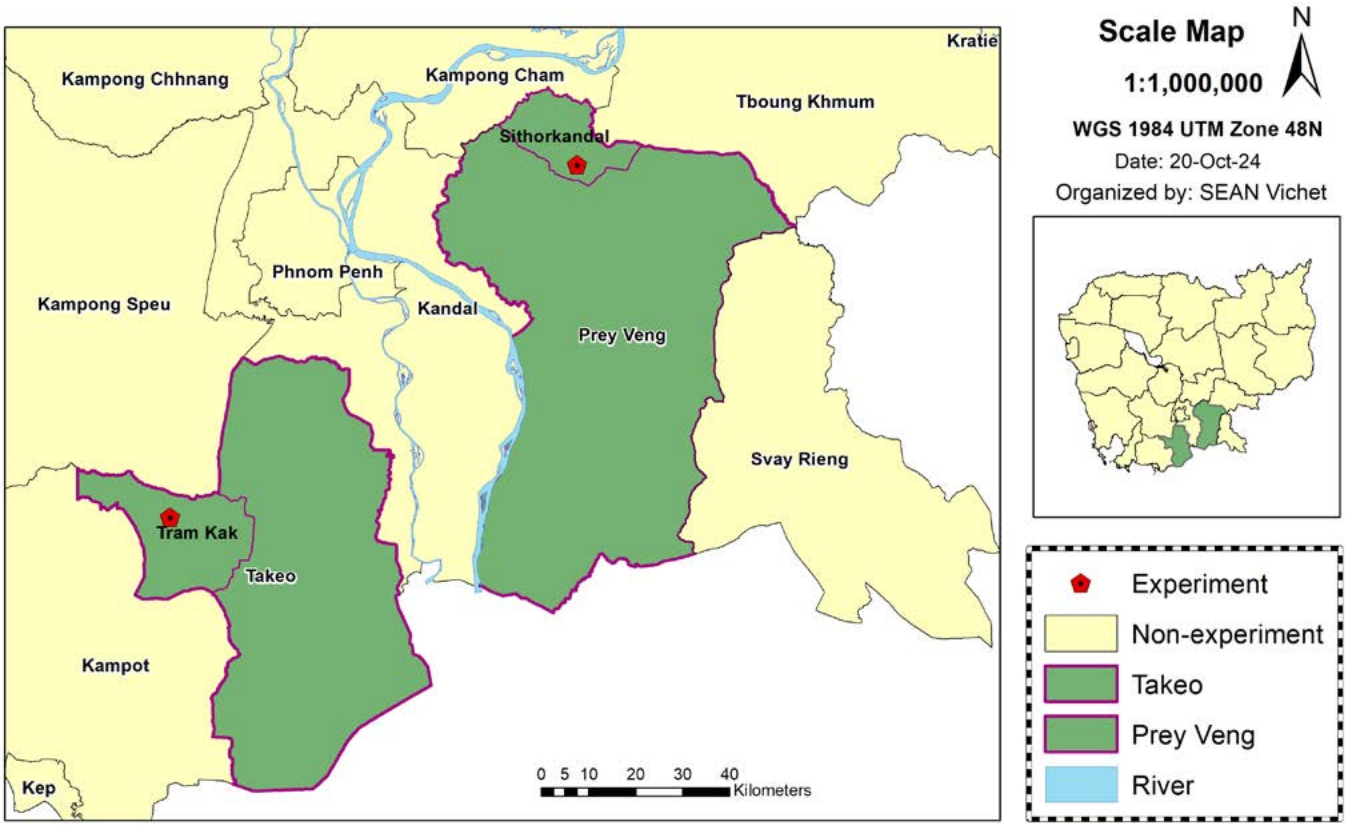
2.1. Study Sites

The experiment was designed with two types of production, consisting of rice-field fisheries (rice-field pond) and a rice crop. Trial farmers were selected from households that have a rice-field pond within 0.5 –3 km from a CFR and which was dug one or more years before the intervention. In addition to ensuring no fish are stolen, the pond had to be close to the house or managed by the farmer. The fish were stocked from the wild. However, the pond had to have at least one fish inlet that connected it to the rice field or canal.

Wild snakehead, climbing perch and walking catfish were released into the pond at a stocking density of 0.5/m^2. This was based on discussion with communities and the FiA staffs. The stocked fish were small, at 5-100 g each.

The farmers were selected from Svay Teab and Peanea, which are influenced by the Boeng Plang CFR, and Ang Baksei, which is influenced by Srei Kru, Kpob Trabek and Tour Toeng Thngai CFRs.

Figure 1. Location of the rice-field pond experiment.



2.2. Experiment Design

The experiment was designed with two main components:

- **Rice-field fisheries (rice-field pond):** Farmers were selected based on the proximity of their ponds to a CFR. The experiment compared two treatments:
    1. **T1 (improved practices):** This involved mechanized row direct seeding, fish shelters, aquatic plants, and controlled stocking of wild fish.
    2. **T2 (farmer practices):** This involved using traditional methods with no additional interventions.
- **Rice crop:** This was integrated into the fisheries component to evaluate the combined effect on overall productivity.
    1. **T1 improve for rice:** seed rate, row seeding
    2. **T2 T2 (farmer practices):** This involved using traditional methods with no additional interventions

The experiment was designed to evaluate the climate-resilient production and economic performance of the rice–fish system by comparing the seed rate options integrated with marketable fish species. Two treatments were used, as shown in Table 1.

Plate 1. A rice-field pond improves habitat and fish migration.

Table 1. Summary of specific rice-field fisheries (trap-pond) practices used for the pilot trial.

Treatment		T1 (improved practices)	T2 (farmer practices)
I. Rice			
1	Seed rate	80 kg/ha^{-1}	200 kg ha^{-1}
	Rice variety	Short-duration cultivar	Short-duration cultivar
2	Crop establishment	Mechanized row direct seeding	Broadcast by hand
II. Fish			
3	Fish species	Wild fish plus the release of 0.5 fish/m^2 at the per species (snakehead, climbing perch, and walking catfish) into the pond	Wild fish
4	Fish feed	Natural feed (insects)	Natural feed (insects)
5	Habitat	Aquatic plants grown to cover 30%–40% of the pond and the edge of the pond, with shelter added to protect the fish	No intervention
6	Inlet–outlet	At least two fish inlets–outlets	No intervention

2.3. Project Intervention and Farmer Support

Depending on the appropriate time and planting season, the experimental project facilitated the implementation of rainfed rice production for farmers in each province as follows:

The farmers contributed or committed to the experiment in the following ways:

- They owned pond and prepared the pond.
- They managed the pond to ensure someone did not steal the fish.

- They improved the pond (inlet–outlet, grow/or remove aquatic plants) and the project paid for it.
- They collected snakehead and released it into the pond, and the project paid for it.
- They kept regular records in a logbook (stocking, harvest, labor, water quality, etc.), and the project provided them support with a book, pen, and other materials.
- They observed and tested the water in the pond regularly. The farmers could not harvest the fish before February 2024. If they did, they had to get approval from partner staff.
- The farmer could then pump the water, and the project would pay the pumping fee. The fish/OAA collected were counted and weighed before the farmer could use them.
- In addition, the project would provide sowing in their own rice fields near the rice-field ponds:
  - The farmers needed to use mechanized row direct seeding for treatment sites in Takeo, with the project covering the cost of labor.
  - In Takeo, farmers recorded data the planting date for each crop, the harvesting date, expenditures on agricultural inputs, and crop-cut data for rice farming for economic analysis.
- The farmers were required to manage their ponds, prevent fish theft, and record data on fish stocking, harvesting, water quality, and rice crop yield. The project provided financial support for pond improvements, fish stocking, and data recording materials.

Plate 2. A farmer in Takeo monitors the water in his rice field.

2.4. Pond and Water Management

The selected ponds were managed to ensure that aquatic plants covered 30%–40% of the pond (Kim et al., 2019) for fish shelter, especially during the dry season and whenever fish were present in the pond. Moreover, whenever the pond was not connected to floodwaters, the fish ate food like small fish species, insects, and plankton until harvesting (Table 2).

Table 2. Trial work plan.

Activities	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Selecting ponds	■	■	■									
Making preparations for the pond and for fish migration			■	■								
Establishing rice crops				■	■							
Managing aquatic plants to improve water quality (enhancing food available in the food chain)				■	■	■						
Releasing additional fish							■	■				
Managing the pond					■	■	■	■	■	■	■	
Harvesting rice							■	■				
Harvesting fish										■	■	
Hosting a field day event										■	■	

3. Data Collection

To ensure a comprehensive assessment of the experiment, data were meticulously collected on a regular basis across several key aspects:

- **Fish stocking and harvesting:** Detailed records were maintained throughout the fish stocking and harvesting phases. Before stocking, fish were weighed and counted to establish baseline metrics, ensuring that only healthy and appropriately sized fish were selected for release into the ponds. This careful selection process was aimed at maximizing survival rates and optimizing growth potential. During harvesting, the fish were again weighed and counted to measure growth rates, and overall yield. This comparison between pre- and post-stocking data provided valuable insights into the effectiveness of the pond management practices and the health of the fish populations.
- **Water quality monitoring:** Water quality was a critical factor in the success of both the fish and rice components of the experiment. To monitor this, water transparency, pond depth, and adjacent rice field water levels were recorded at least twice a month. Water transparency measurements provided insights into the clarity of the water, which is essential for maintaining a healthy aquatic environment, particularly for the growth of plankton and other small organisms that form the base of the pond's food chain. Pond depth was monitored to ensure that the water levels remained sufficient to support fish survival, especially during the dry season. Additionally, the water levels in the adjacent rice fields were tracked to assess the relationship between pond water management and rice crop hydration.
- **Rice crop yield and economic data collection:** Comprehensive data were gathered on rice crop performance to evaluate the impact of the integrated farming system. At the time of harvest, the rice yield was meticulously recorded, including the total output per hectare. Alongside yield data, the economic aspects of rice farming were documented, capturing the price at which the harvested rice was sold and detailing all input costs, such as those for fertilizers, pesticides, labor, and water management. This information was crucial for conducting an economic analysis of the rice farming practices, allowing for a comparison between different treatments and the identification of the most cost-effective and productive approaches.

Plate 3. Farmers release fish into their rice-field pond in Prey Veng.

4. Results and Findings

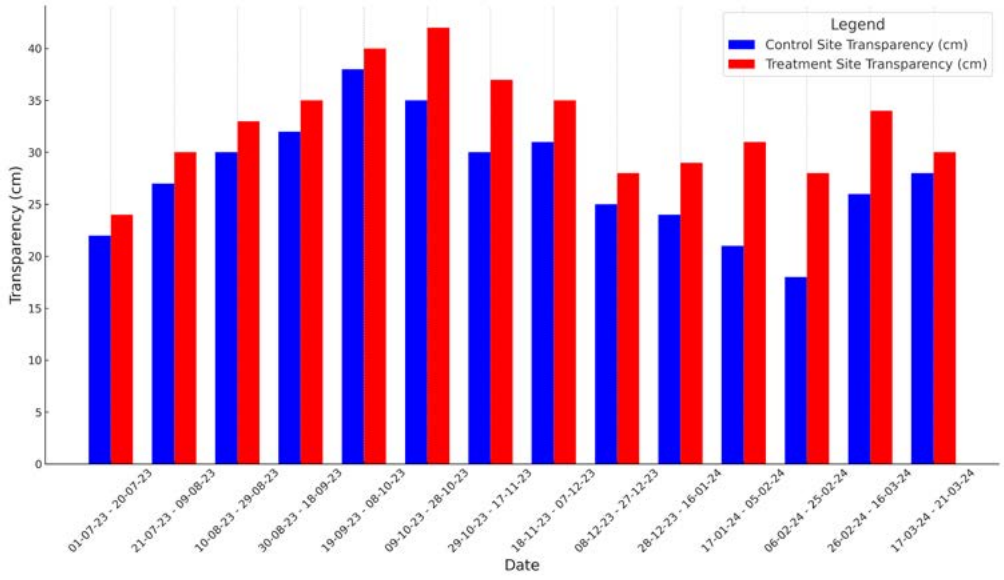
4.1. Water Quality Monitoring

Water quality is a crucial determinant of both fish health and rice crop productivity in integrated farming systems. To ensure a comprehensive understanding of the environmental conditions within the rice-field ponds, water quality data were systematically recorded, with a focus on several key parameters.

4.1.1.Water Transparency

The data showed fluctuations in water transparency, which can impact the growth of plankton and the overall food chain within a pond.

Figure 2. Water transparency in the rice-field pond experiment.



The bar graph in Figure 2 compares the water transparency (measured in centimeters) between the control and treatment sites over the course of the study period, which ran from July 2023 to March 2024. Transparency is a key indicator of water quality and can provide insights into factors such as sediment load, algal growth, and overall pond health.

At the control sites, water transparency generally fluctuated between 21 and 35 cm. The transparency started at around 22 cm in early July 2023 and gradually increased, peaking at 35 cm in October 2023. Following this peak, transparency slightly decreased and then varied between 18 cm and 31 cm during the dry season, which likely reflects changes in water quality caused by factors like reduced water volume, increased sedimentation, or biological activity because of more fish being released into the pond.

The treatment ponds exhibited higher water transparency throughout the study period, suggesting that the interventions applied at the sites (which could include better management practices, reduced sediment input, or improved pond maintenance) were effective in maintaining clearer water. The peak transparency for both control and treatment ponds occurred in October, likely corresponding with seasonal changes such as the end of the rainy season when sedimentation rates may decrease, leading to clearer water.

During the dry season (December 2023 to March 2024), the treatment sites maintained higher transparency levels than the control sites, which indicates that the treatment measures were effective even under challenging conditions, especially when there were aquatic plants, which can reduce erosion and absorb the sediment.

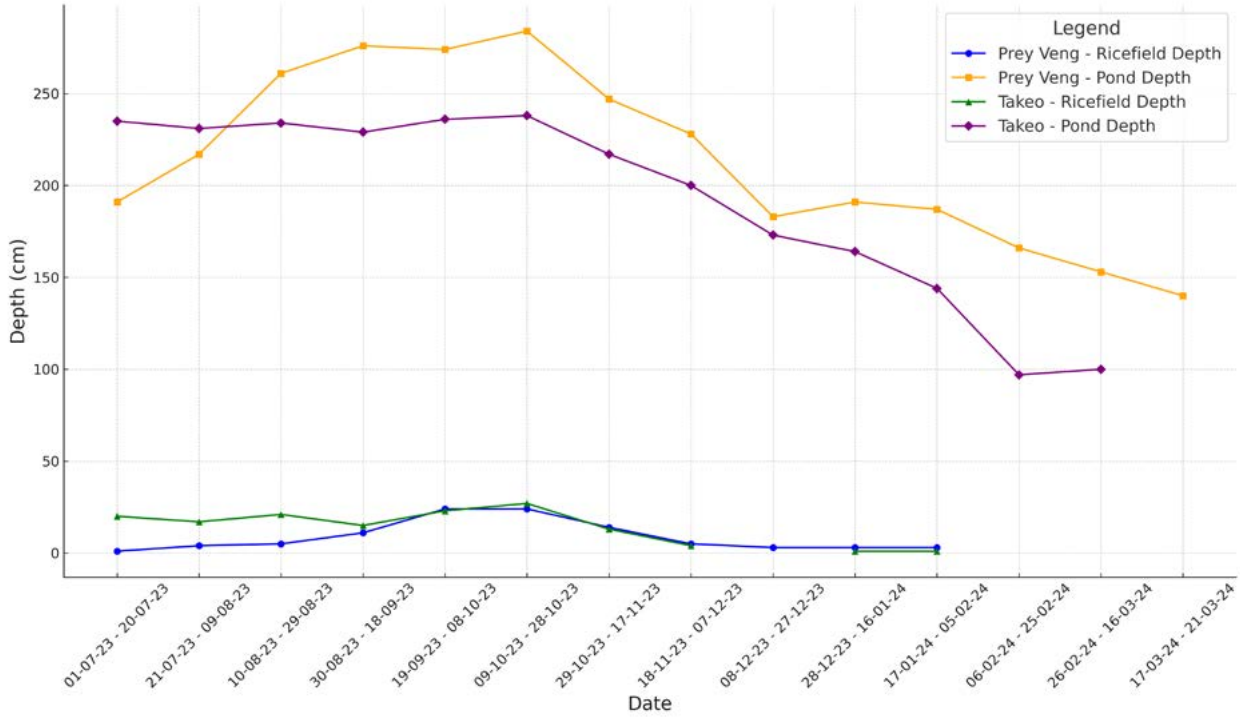
Higher water transparency in the treatment ponds suggests better water quality, which is essential for healthy aquatic ecosystems and can positively impact fish growth and overall pond productivity. The consistent advantage of the treatment ponds over the control sites throughout the study period highlights the importance of implementing effective pond management strategies to sustain water quality, especially during the dry season when conditions are less favorable.

4.1.2. Depth of Rice Fields and Ponds

Pond depth was a critical parameter monitored throughout the experiment to ensure a stable environment for fish, particularly during the dry season when water levels naturally decrease. Maintaining adequate depth helps prevent overheating and oxygen depletion, which are vital for fish health. Depth measurements also provided insights into the pond's water retention capacity, which is crucial for both fish survival and rice crop success, especially during droughts or low rainfall.

Additionally, water levels in adjacent rice fields were recorded to assess the effectiveness of water management at supporting rice growth and optimizing productivity in the integrated farming system. By correlating pond depth with water levels in the rice fields, the study sought to identify optimal water allocation practices to maximize the benefits of the system. However, the ponds were harvested whenever the depth dropped 1 m to ensure it would not affect fish growth.

Figure 3. Depth of the rice fields and ponds during the experiment period.



The experiment, which was conducted between July 2023 and March 2024, focused on monitoring the depth of the rice fields and ponds in the Prey Veng and Takeo provinces of Cambodia. The depth measurements, taken at regular intervals, provided insights into the seasonal fluctuations, the impact of environmental factors on water retention in these agricultural landscapes, and the practices of dry season rice cultivation.

In Prey Veng, the depth of the rice fields remained relatively shallow throughout the study, ranging from just 1 to 24 cm. The minimal depth during the rainy season suggests that the rice fields in this region less rainfall this location compare to Takeo. Conversely, the trap ponds in Prey Veng showed greater depth, with values peaking at 284 cm in late October 2023. This indicates that the trap ponds were capable of maintaining higher water levels.

Takeo presented a slightly different profile. The depths of the rice fields in this province were marginally higher than those in Prey Veng, with depths ranging from 1 to 27 cm. The trap ponds in Takeo demonstrated depth, although slightly less than those in Prey Veng, with a maximum depth of 238 cm recorded in late October 2023. These ponds also play a crucial role in sustaining agricultural activities during the dry season, providing the necessary water resources for irrigation.

Across both provinces, the depths of the trap ponds generally followed a similar trend, peaking around October and then gradually declining. This trend likely reflects seasonal rainfall patterns, evaporation rates, no/less rainfall, and water usage for irrigation, particularly for dry season rice cultivation. These insights could guide future interventions aimed at improving water management in Cambodia's rice fields and trap ponds, ultimately contributing to greater agricultural resilience and productivity, particularly in the face of changing climatic conditions and the ongoing practice of dry season cultivation.

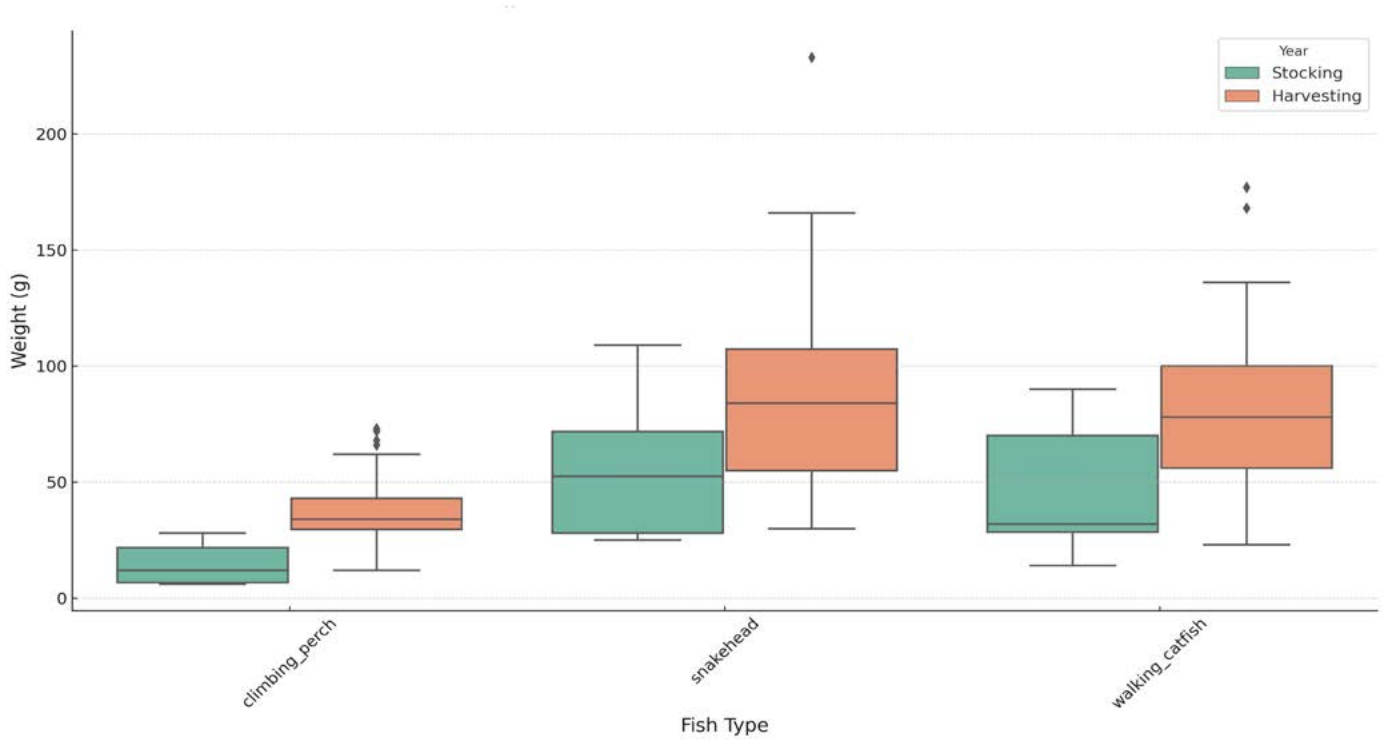
4.2. Fish Growth

The fish were released into the ponds at the beginning of the dry season, around the end of 2023, and were allowed to grow over approximately three months. They were supposed to all be harvested in March 2024, but the ponds in Takeo had to be harvested early, in late February, because they had dropped to the minimum acceptable depth, which would affect fish growth. During this time, the fish remained in the pond, where they fed on natural food created during the wet season, such as insects, zooplankton, plants, and prey fish.Fish Weight by Species

4.2.1. Fish Weight by Species

The fish released into the treatment ponds were carefully measured to determine the maximum, minimum, and average weight for each species at the time of stocking. This baseline data provided valuable insights into the initial size distribution of the fish. Throughout the growing period, special attention was given to monitoring fish growth. At the time of harvesting, which occurred after approximately three months, the weight of each fish was recorded individually, focusing on fish that had been marked. This detailed recordkeeping allowed for a precise assessment of the growth performance of each species, helping to evaluate the effectiveness of the natural feeding environment and the overall management practices applied during the cultivation period.

Figure 4. Weight of fish after being released into a rice-field pond.



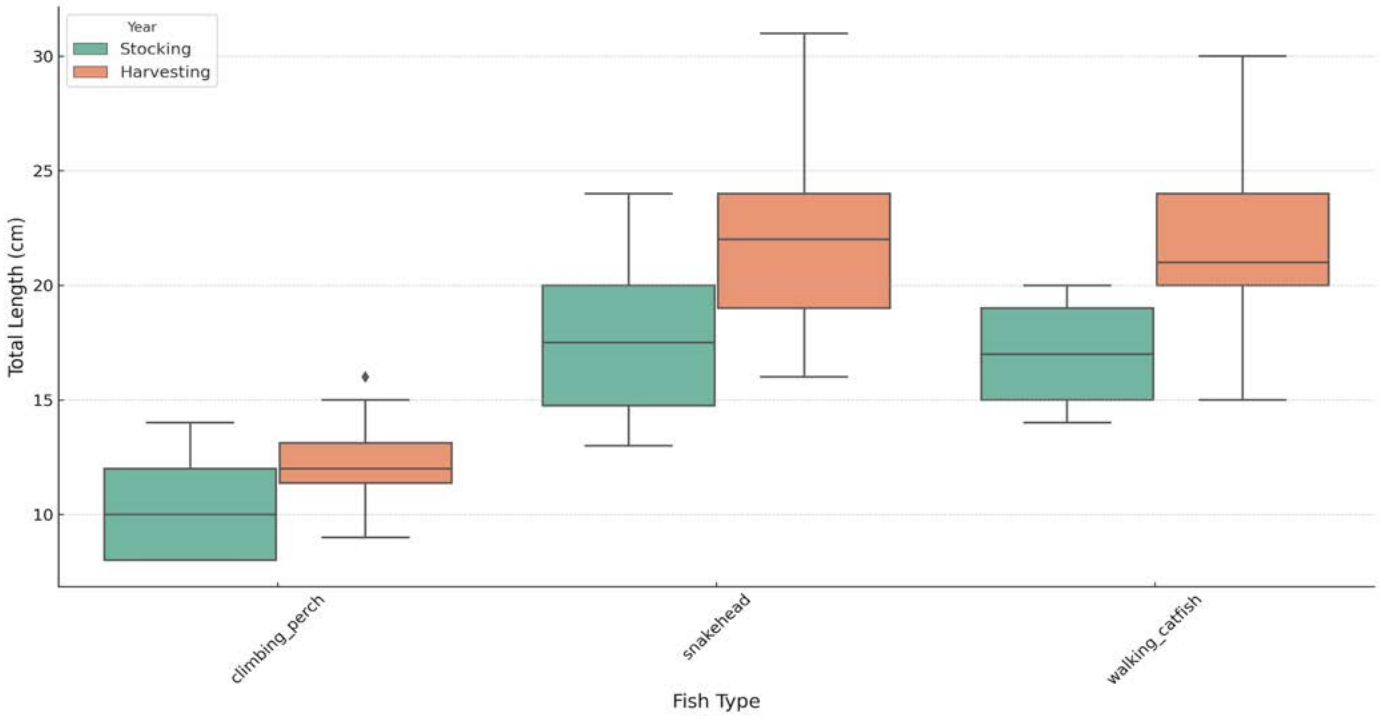
Climbing perch exhibited a noticeable increase in weight from stocking to harvesting, with the median weight in 2024 higher than in 2023, although the overall range was narrower compared to the other species. Snakehead demonstrated substantial growth, with an increase in both the median and the overall range of weights from 2023 to 2024, showing the most substantial gain, as reflected by the wider spread of the box plot in 2024. Similarly, walking catfish displayed considerable growth, with the 2024 distribution showing a higher median and broader range, indicating that many individuals reached much larger sizes compared to the stocking phase. Among the three species, walking catfish had the highest average weight gain of 34.66 g, followed by snakehead with an average gain of 31.15 g, while climbing perch had the lowest average gain at 23.13 g.

The analysis indicates that walking catfish experienced the most growth, on average, followed by snakehead, with climbing perch showing the least gain. The data suggest that all three species experienced growth between the 2023 stocking and 2024 harvesting periods. The substantial increases in both average and maximum weights across the three species point to favorable environmental conditions, effective management practices, and natural feed that supported the growth of the fish.

4.2.2. Fish Length by Species

The fish released into the ponds were measured to determine the maximum, minimum, and average total length for each species at the time of stocking. During the harvesting phase, the total length of each individually marked fish was carefully recorded. This detailed measurement process provided valuable insights into the growth patterns of each species, allowing for a precise comparison between the lengths at stocking and harvesting.

Figure 5. Length of fish after being released into a rice-field pond.



Climbing perch exhibited a noticeable increase in total length from stocking to harvesting, with the 2024 data showing a higher median and an overall increase in the total length range. Snakehead showed a substantial increase in total length from 2023 to 2024, with the harvesting data revealing a broader distribution and a higher median length. Similarly, walking catfish displayed growth in total length, with the 2024 distribution being considerably larger than in 2023, as indicated by the box plot.

All three species showed growth in total length from stocking to harvesting, with walking catfish and snakehead exhibiting the most increases in length. Climbing perch also demonstrated growth, although to a lesser extent compared to the other two species. Walking catfish gained the most length, with an average increase of 4.76 cm from stocking to harvesting. This was followed by snakehead with an average gain of 3.75 cm, and climbing perch with the smallest gain of 2.09 cm. Upon observation, there were no clear benefits from stocking, as the total weight at harvest was not greater than the weight stocked. However, it is important to note that we faced limitations in identifying all marked fish, as some fin marks may have regrown, and some fish were not collected during the harvest.

4.3. Fish Harvesting

During the harvesting phase, in addition to sampling, the weight and number of all harvested fish from each species were meticulously recorded. This comprehensive data collection allowed for a thorough assessment of the overall yield. The information gathered was crucial for understanding the growth performance of the fish and determining the best use of the catch. The harvested fish were weighed and counted by species. Depending on their size and quality, the fish were either sold for profit, consumed by the household, or given to neighbors, ensuring that the economic returns were maximized.

4.3.1. Weight of Harvested Fish

The weight varied across the ponds, with average yields differing between the improved practices (T1) and traditional methods (T2). Yields were calculated in kilograms per square meter, allowing for a clear comparison of productivity between the two approaches.

Figure 6. Average weight (kg) of fish in rice-field ponds per square meter.

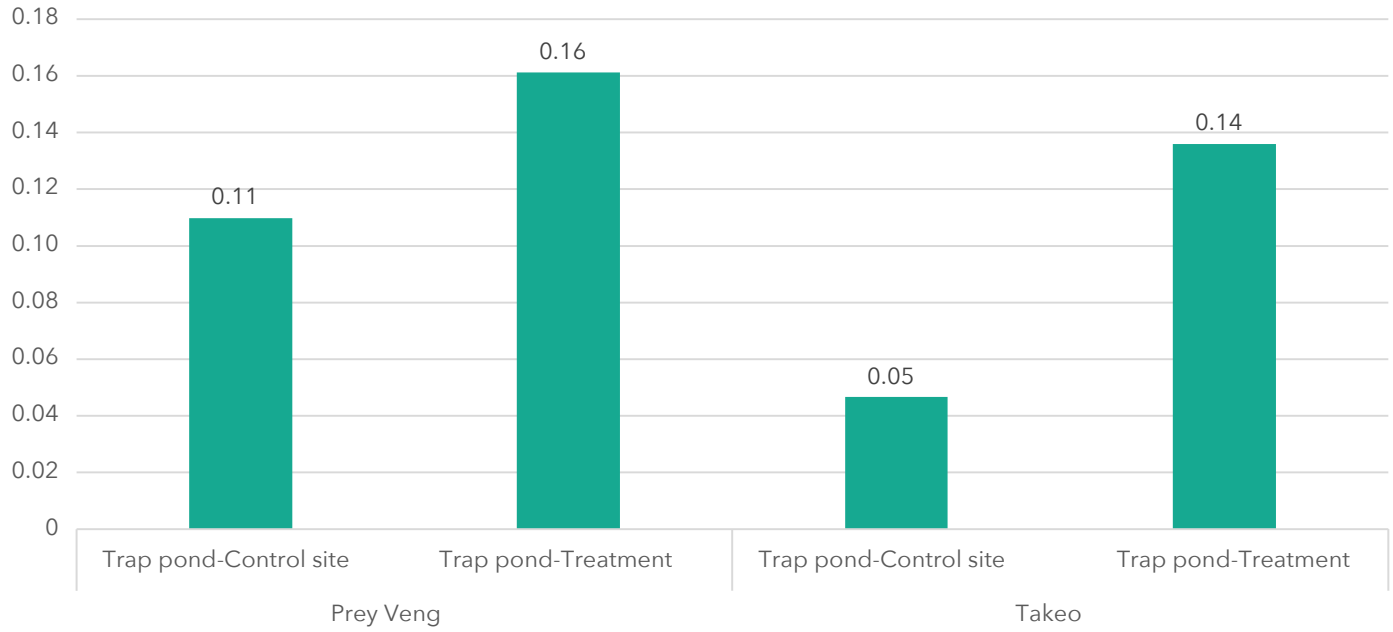


Figure 6 illustrates the average weight of fish caught per square meter in pond areas across Prey Veng and Takeo, comparing control sites to treatment sites. In Prey Veng, the control site showed an average fish weight of 0.11 kg/m^2, while the treatment site saw an increase, with an average of 0.16 kg/m^2. This indicates a notable improvement in fish productivity at the treatment site compared to the control site.

In Takeo, the control site exhibited a much lower average fish weight of 0.05 kg/m^2, suggesting less productive conditions than in Prey Veng. However, the treatment site in Takeo also showed a dramatic increase, with an average fish weight of 0.14 kg/m^2, similar to the treatment results in Prey Veng. This increase demonstrates that the treatment had a strong positive impact, especially in Takeo, where the initial productivity was lower.

Overall, the data presented in Figure 6 underscores the effectiveness of the treatment applied, as it consistently led to higher fish weights in both locations. The improvements are particularly pronounced in Takeo, where the control site's productivity was initially much lower. These results suggest that the treatment could be a valuable strategy for enhancing fish productivity in similar pond environments.

Figure 7. Number of fish yield in the rice-field ponds per square meter.

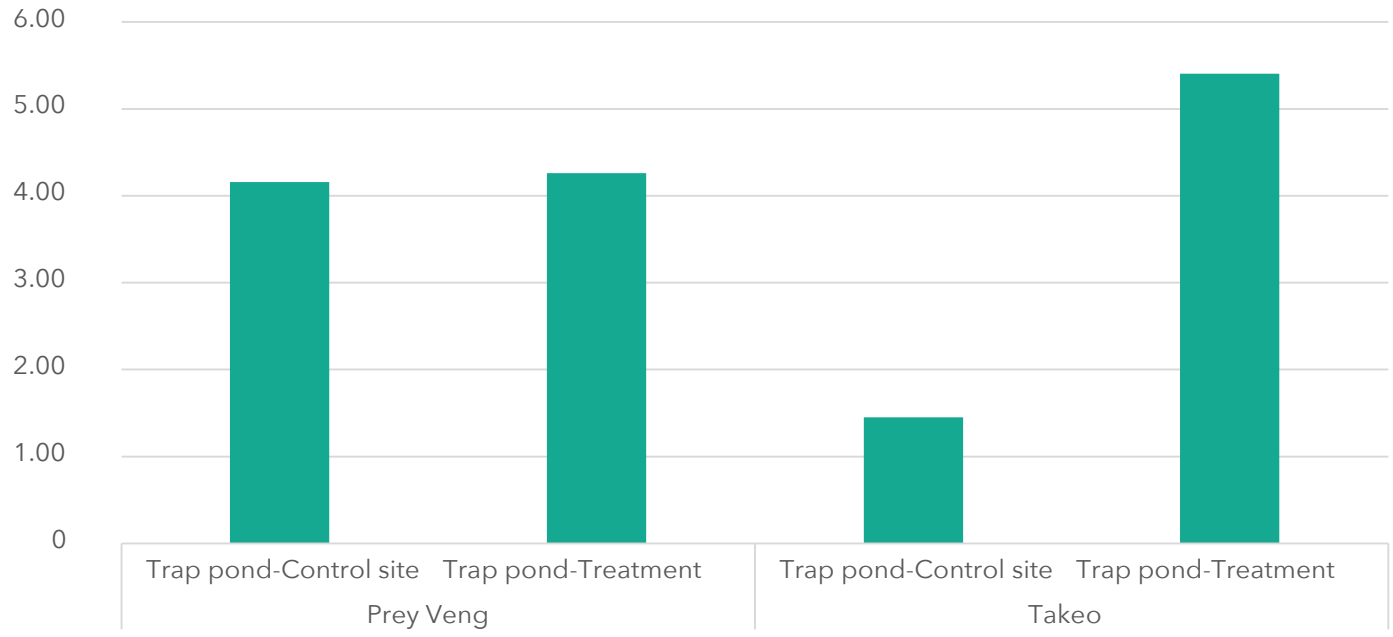


Figure 7 presents the average number of fish caught per square meter in pond areas across Prey Veng and Takeo, comparing control sites to treatment sites.

In Prey Veng, both the control site and the treatment site showed a similar average number of fish per square meter, around 4/m². However, this outcome may have been influenced by the fact that the ponds in Prey Veng were harvested earlier. This could have resulted in more prey fish remaining in the control site, which could have balanced out the fish numbers between the control and treatment sites, thus masking the potential impact of the treatment.

In contrast, Takeo displayed a more pronounced difference between the control site and the treatment site. The control site had a lower average number of fish, about 2/m², which was less than in Prey Veng. However, the treatment site in Takeo showed a substantial increase in the average number of fish, reaching around 5/m².

The data suggest that the treatment's effect on fish quantity was greater in Takeo than in Prey Veng. In Prey Veng, early harvesting may have led to more prey fish in the control site, thereby reducing the observable impact of the treatment. In Takeo, the treatment led to a marked increase in the number of fish per square meter, indicating that the ponds were initially less productive and more responsive to the treatment. This emphasizes the importance of contextual factors, like harvesting time, when evaluating the effectiveness of treatments on fish populations.

4.3.2. Species Diversity

Snakehead, climbing perch, and walking catfish were the primary species intentionally stocked in the ponds and were chosen for their strong market demand and growth potential. These species were also already present in the ponds before the stocking process, indicating a naturally supportive environment for their growth. In addition to these primary species, the ecosystem of the ponds supported a variety of other fish, including three-spot gourami and mystus. The presence of these additional species reflects the biodiversity of the pond and suggests that the aquatic environment was conducive to sustaining a range of fish. This diversity could contribute to the overall health of the ecosystem, potentially offering benefits such as natural pest control and additional sources of food for the stocked fish.

Figure 8. Number of fish species in the rice-field ponds.

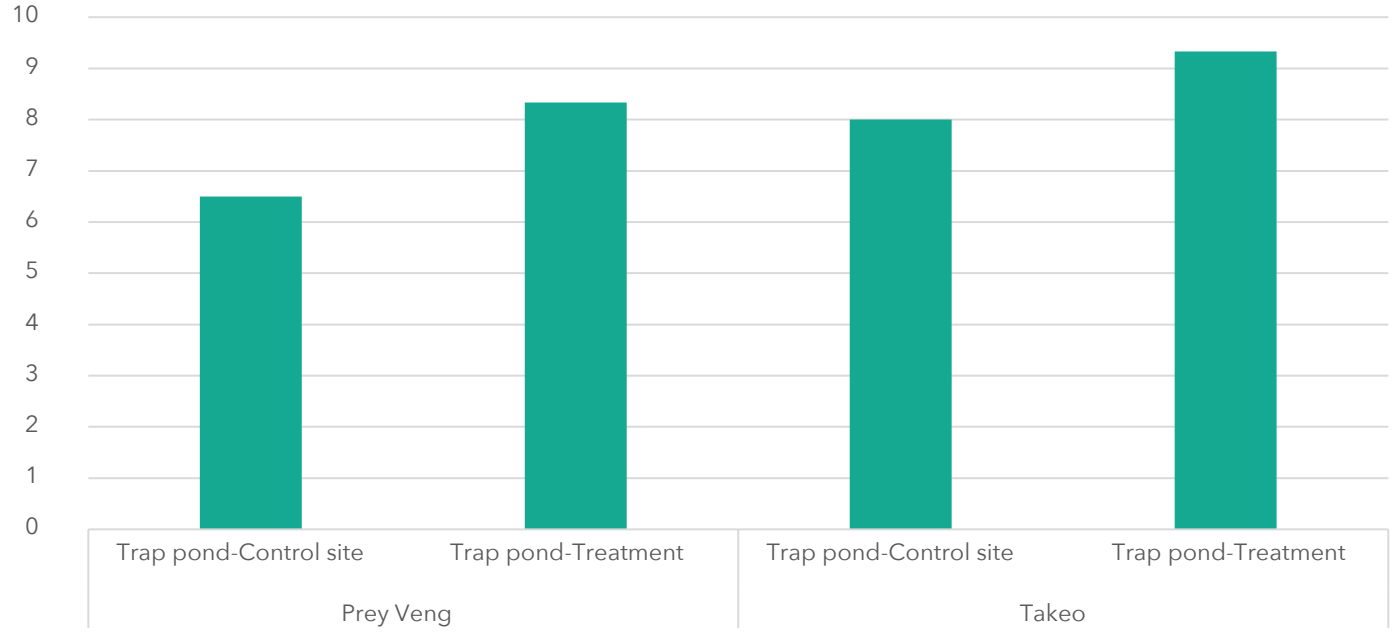
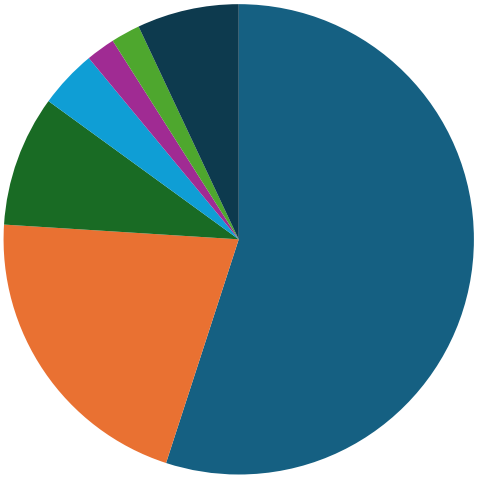


Figure 8 shows the average number of fish species per pond across Prey Veng and Takeo, comparing control sites to treatment sites.

In Prey Veng, the control site had an average of around 7 fish species per pond, while the treatment site had a slightly higher average of about 8. In Takeo, the control site showed an average of around 8 fish species per pond, which was similar to the treatment site in Prey Veng. However, the treatment site in Takeo showed a further increase, with an average of around 9.

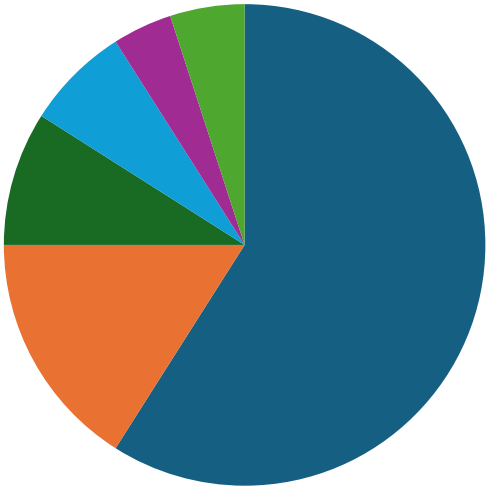
The data indicate that the treatment applied in both Prey Veng and Takeo resulted in an increase in the number of fish species compared to the control sites. The effect of the treatment is more pronounced in Takeo, where the difference between the control and treatment sites is slightly larger. This suggests that the treatment was effective in enhancing the fish populations in both locations, with a potentially stronger impact in Takeo. The consistent increase across both locations supports the idea that the treatment is beneficial for improving fish productivity in these types of pond environments.

Figure 9. Proportion of fish caught in the treatment ponds.



- Snakehead (55%)
- Walking_catfish (21%)
- Climbing_perch (9%)
- Threesport_gorami (4%)
- Rasbora (2%)
- Mytus (2%)
- Other_six (7%)

Figure 10. Proportion of fish caught in the control ponds.



- Snakehead (59%)
- Walking_catfish 16%)
- Climbing_perch (9%)
- Threesport_gorami (7%)
- Rasbora (4%)
- Mytus (5%)

The pie chart in Figure 9 indicates that snakehead was the most dominant species in the treatment pond, comprising 55% of total fish caught. This suggests that either the pond environment or the treatment applied is highly favorable for snakehead. The walking catfish followed as the second-most abundant species, accounting for 21% of the catch, which, although significant, was much lower than the proportion of snakehead. Climbing perch was the third-most common species, making up 9% of the total catch, while three-spot gourami constituted 4%. Both rasbora and mystus represented 2% each of the fish population in the ponds. The remaining 7% was composed of six other species that were grouped together, indicating their lesser prevalence in the ponds. This distribution suggests that while the ponds support a variety of species, certain conditions, possibly influenced by the treatment, favor the proliferation of snakehead and walking catfish, in particular.

The chart also reveals that the treatment ponds were predominantly inhabited by snakehead and walking catfish, which together made up more than three-quarters of the total catch (76%). The presence of a variety of other species in smaller proportions suggests that while the ponds supported a diverse range of fish, the conditions or treatment applied may have particularly favored certain species like snakehead and walking catfish.

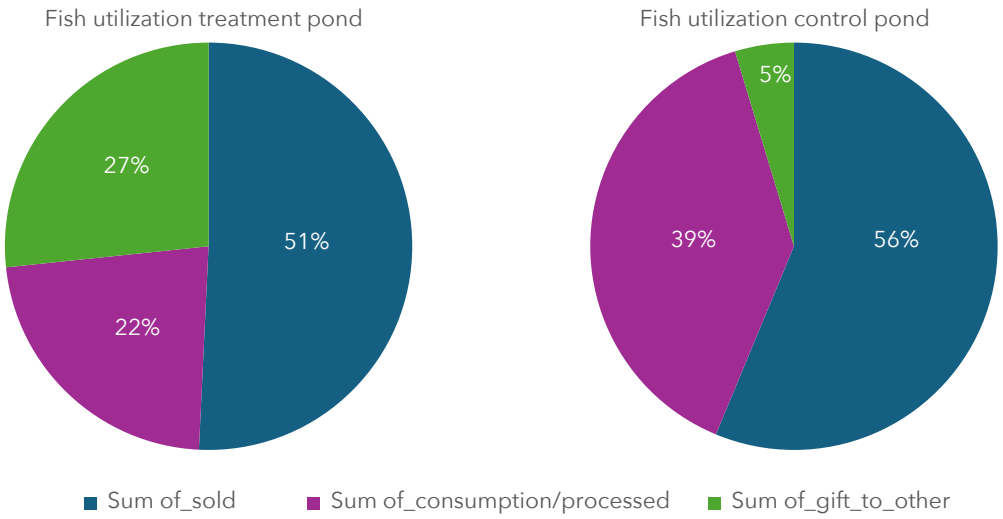
The pie chart in Figure 10 displays the proportions of different fish species caught in the control ponds, highlighting the natural distribution of these species without the influence of any treatment. Snakehead emerged as the most dominant species in the control ponds, accounting for 59% of total fish caught. This suggests that snakehead is naturally prevalent in this pond environment, indicating its adaptability and dominance even in the absence of any interventions. Climbing perch was the second-most abundant species in the control ponds, making up 16% of the catch. This is a higher proportion than what was observed in the treatment ponds, indicating that climbing perch thrives more in the control environment. Three-spot gourami constituted 9% of the catch and walking catfish represented 7% of the fish caught in the control ponds, which was notably lower than the 21% observed in the treatment ponds. This difference suggests that walking catfish benefits more from the treatment environment, where it is better supported or more competitive. On the other hand, rasbora made up 4% of the catch in the control ponds, which was double its proportion in the treatment ponds, indicating that it might be less competitive or less favored in the treatment environment. The remaining 5% of the catch consisted of three other species grouped together, reflecting their minor presence in the ponds.

Overall, the data for the control ponds show that while snakehead dominated in both provinces, the species composition in the control ponds differed from the treatment ponds. The higher proportions of climbing perch and rasbora in the control ponds contrast with the increased presence of walking catfish in the treatment ponds, illustrating how the treatment influenced the ecological balance within the pond. These observations provide valuable insights into how different species respond to environmental changes, whether natural or induced by treatment. Moreover, the control ponds were harvested earlier, which lead to there being more prey fish than in the treatments, which were harvested around two months later.

4.3.3. Utilization

A portion of the harvested fish was consumed by the households, with some being sold or given as gifts, contributing to household nutrition and income.

Figure 11. Proportion of fish caught in the rice-field ponds.



The two pie charts in Figure 11 illustrate the percentage of fish utilization from the treatment ponds and the control ponds, categorizing fish utilization into three main activities: sale, consumption or processed, and gifted.

Treatment ponds:

- The majority of the fish from the treatment ponds were sold, accounting for 51% of total utilization. This indicates that fish harvested from these ponds are primarily sold.
- A smaller portion, 22%, of the fish were used for consumption or processing. This suggests that while a small amount is kept for personal use or local processing, it is not the primary purpose.
- The remaining 27% of the fish were given as gifts to others, showing that a substantial portion of the catch is shared within the community or with relatives and friends.

Control ponds:

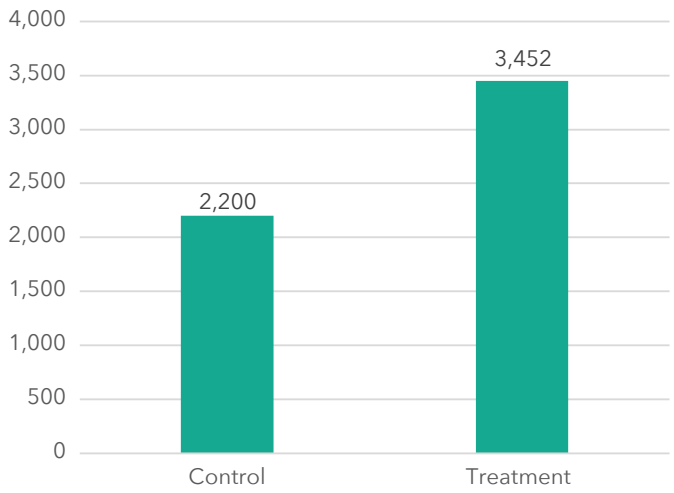
- In the control ponds, an even larger proportion of the fish, 56%, was sold. This suggests that selling is even more dominant in the utilization of fish from the control ponds compared to the treatment ponds.
- A considerable portion, 39%, of the fish from the control ponds was used for consumption or processing, which was higher than in the treatment ponds. This indicates a stronger emphasis on using the fish in the control ponds for personal or local use.
- Only 5% of the fish from the control ponds were given as gifts, much lower than the 27% in the treatment ponds. This suggests that fish from the control ponds are less frequently shared with others because they are caught less and other farmers in Prey Veng have middlemen to buy them during harvesting.

The main difference between the two types of ponds lies in how the fish were utilized. Although selling was the dominant use in both types, it was slightly more prominent in the control ponds. The treatment ponds showed a higher proportion of fish being gifted to others (27% vs. 5%). In the control pond in Prey Veng, middlemen came directly to the pond to purchase the fish, which reduced the proportion of fish that were gifted. In contrast, during the harvest in the treatment pond, many people from the community came to help with the harvest, and the pond owner gave them fish as a gift for their assistance. This reflects a stronger sense of social activity and community involvement in treatment pond. Conversely, the control pond has a higher percentage of fish used for consumption or processing (39% vs. 22%), indicating that more fish are kept for personal use in this environment. These differences may reflect variations in the availability of fish, the influence of the treatment, or differing cultural practices between the two pond environments.

4.4. Rice Crop Yield

Data for rice crop yield highlight the impact of different agricultural practices on productivity. The comparison between T1 (improved practices) and T2 (farmer practices) demonstrates that the introduction of technologies like mechanized seeding and better water management enhances yield per hectare, as shown in Figure 12.

Figure 12. Rice Crop Yield Kg/Ha/Cycle.



The data for rice crop yield in Figure 12 shows clear differences in productivity between the treatment and control ponds, which can be linked to improvements in both fish and rice:

- **T1 (improved practices)**: This treatment, which yielded 3,452 kg/ha per cycle, reflects the benefits of enhanced agricultural practices. These improvements likely include the integration of fish into rice fields, mechanized seeding, and better water management. The introduction of fish into the rice ecosystem can enhance soil fertility and pest control, contributing to the observed increase in rice yields.
- **T2 (farmer practices)**: With a yield of 2,200 kg/ha per cycle, this control represents traditional practices without integrating newer techniques seen in T1. The lower yield underscores the potential benefits that could be realized by adopting fish integration and other modern practices in rice farming.

The data highlight that the combination of rice and fish farming, along with other improved practices, can significantly enhance both rice yield and overall agricultural productivity. The results suggest that broader adoption of these integrated practices could lead to substantial gains in both rice and fish production.

4.5. Economic Data

An analysis of economic data plays a crucial role in understanding the financial viability and sustainability of agricultural practices, particularly in the context of integrated farming systems. The following sections provide a detailed economic analysis of fish and rice production—two key components of the agricultural system under study. By examining the economic performance of these activities, we can gain insights into their profitability, cost-efficiency, and overall contribution to the livelihoods of the farmers involved. Based on the new minimum wage of $204 per month, the labor cost per hour for workers in Cambodia is approximately $0.98 per hour. This was derived using the standard calculation for a 26-day work month at 8 hours per day.

For income, it was derived only from fish and rice production. It also accounted for the value of any fish or rice that was consumed or given as gifts by converting them into monetary terms. The term "ARE" is commonly used by local farmers to refer to an area equivalent to 100 m^2. The local currency, the Khmer Riel (KHR), has an exchange rate of approximately 4,000 riel to 1 US dollar.

4.5.1. Fish Economic Analysis

The fish economic analysis focuses on evaluating the financial returns from wild fish, taking into account factors such as input costs, market prices, and revenue generated. This analysis examines the profitability of all fish species, the efficiency of pond management practices, and the impact of treatments on fish production. Key metrics such as cost-benefit ratios, net income, and return on investment are calculated to assess the economic viability of wild fish operations. The findings from this analysis provide valuable insights into the economic incentives for farmers to adopt or continue culturing wild fish as part of their livelihood.

Figure 13. Economic analysis of fish in rice-field ponds (KHR/ARE).

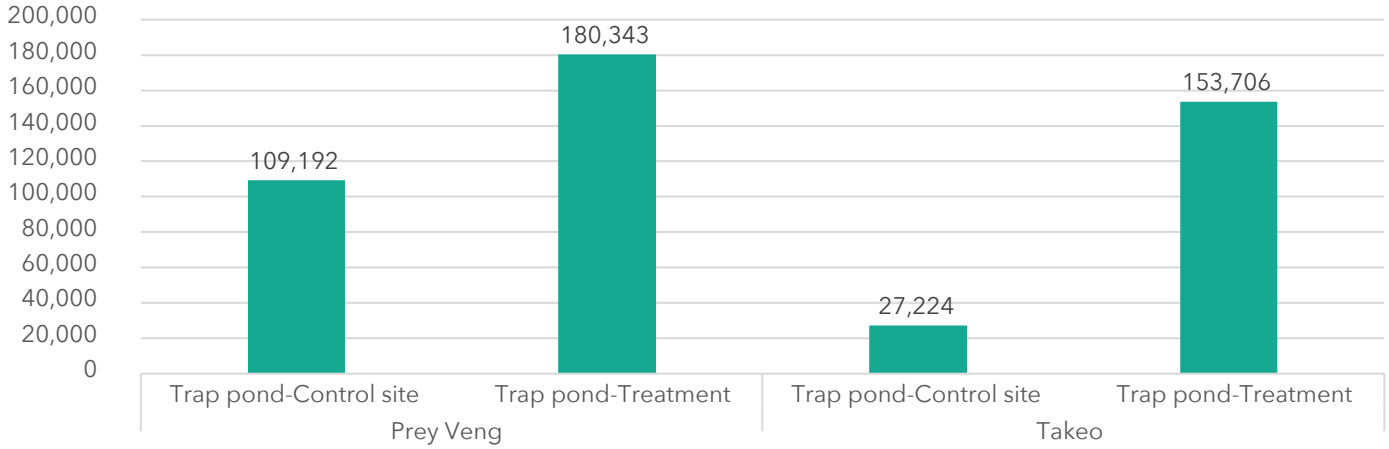


Figure 13 presents an economic analysis of pond management, measured in net profit (KHR/ARE), comparing control and treatment sites in both Prey Veng and Takeo. The analysis provides insights into the financial outcomes of pond management under different conditions. In particular, it highlights the impact of specific interventions.

In Prey Veng, the control site showed a net profit of 109,192 KHR/ARE, reflecting the economic returns under standard pond management practices without any additional treatment. When the treatment was applied, the net profit increased to 180,343 KHR/ARE. This substantial increase can be attributed to interventions such as better pond management, improvements to the pond infrastructure (including inlet and outlet

enhancements), the strategic growth or removal of aquatic plants, and the creation or maintenance of fish habitats. These interventions clearly contributed to a marked improvement in the profitability of pond management in Prey Veng.

In Takeo, the control site exhibited a much lower net profit of 27,224 KHR/ARE, indicating less favorable economic conditions for pond management compared to Prey Veng. However, with the application of similar interventions, the net profit rose sharply to 153,706 KHR/ARE. The improvement in Takeo underscores the effectiveness of these interventions in enhancing economic outcomes, particularly in environments where the baseline profitability is lower. The improvements in pond structure and management practices have been pivotal in driving these economic gains.

Overall, Figure 13 highlights the considerable economic benefits of applying targeted interventions in pond management. Both locations experienced notable increases in profitability, with Prey Veng benefitting from a higher starting point and Takeo seeing a more dramatic enhancement. This analysis demonstrates the potential of strategic pond management interventions—such as infrastructure improvements and habitat management—to boost the financial viability of pond management practices in different regional contexts. However, this analysis was not taken into account regarding depreciation of the ponds.

Figure 14. Detailed listing all costs for fish (KHR/ARE).

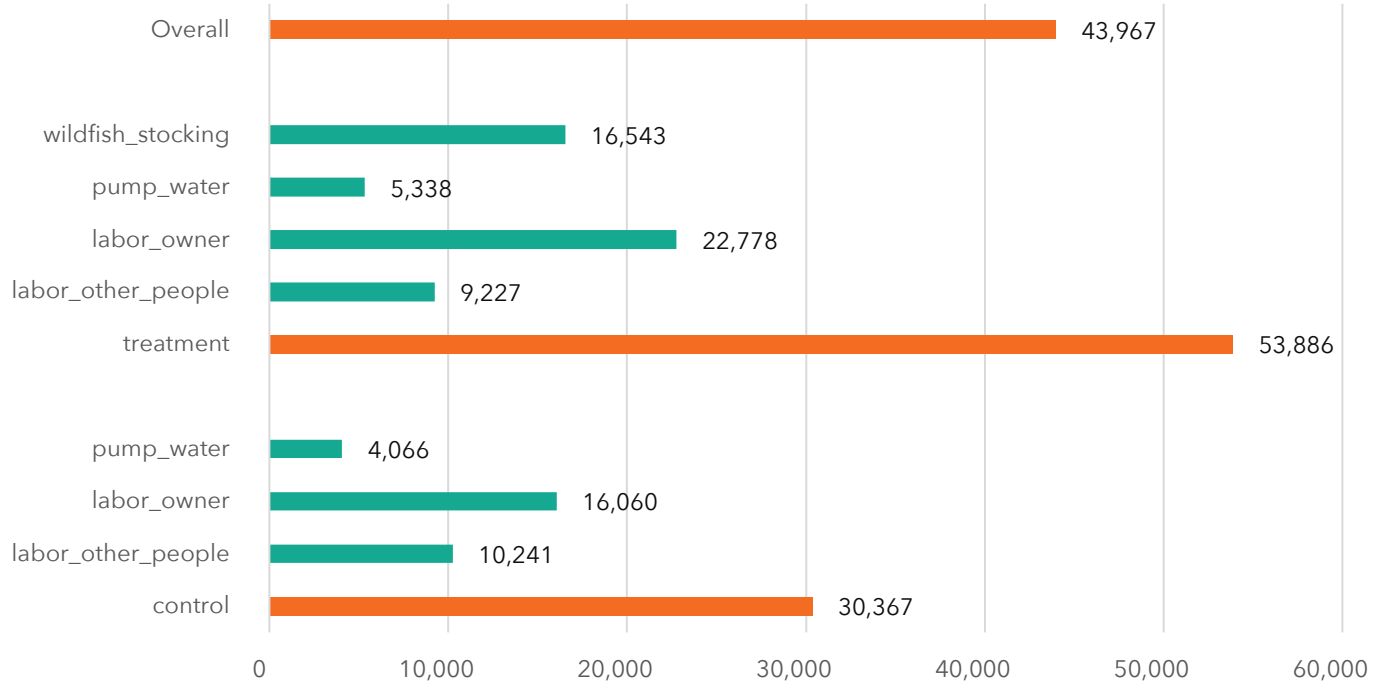


Figure 14 provides a detailed breakdown of costs associated with two farming treatments, measured in KHR/ARE per 100 m^2. The treatment sites incurred the highest overall cost, at 53,886 KHR/ARE, largely from specific interventions like stocking wild fish, which cost 16,543 KHR/ARE and was not done in the control sites. The control sites, representing traditional practices, had a lower total cost of 30,367 KHR/ARE. Water pumping costs were slightly higher in the control sites, at 5,338 KHR/ARE compared to 4,066 KHR/ARE in the treatment, while labor costs for the owner were higher in the control (22,778 KHR/ARE) than in the treatment (16,060 KHR/ARE), suggesting more efficient or mechanized practices in the treatment. Labor costs for hiring other people were similar between the two groups, indicating comparable use of external labor. Overall, the higher costs in the treatment sites were likely because of the additional interventions aimed at enhancing productivity, justifying the increased investment.

4.5.2. Economic Analysis of Rice

An economic analysis of rice involves a similar evaluation process, focusing on the profitability and economic sustainability of rice cultivation. This section examines the costs associated with rice production, including inputs such as seeds, fertilizers, labor, and water management. It also considers the revenue generated from rice sales and any value-added processing that may occur. The analysis seeks to identify the most cost-effective practices and varieties, as well as the overall financial performance of rice farming in the context of the broader agricultural system. By understanding the economic dynamics of rice production, this analysis contributes to optimizing resource allocation and maximizing the economic returns for farmers engaged in rice cultivation.

Figure 15. Economic analysis of rice in the rice fields (KHR/ARE).

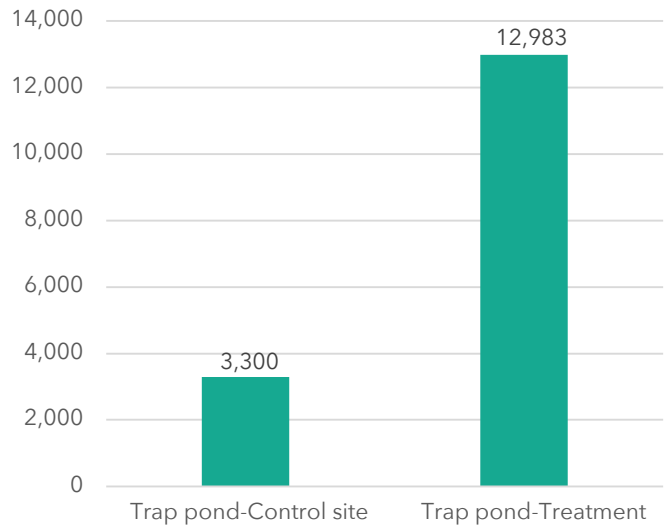


Figure 15 illustrates an economic analysis of rice production, measured in net profit (KHR/ARE), comparing outcomes between the control sites and treatment sites. The control sites, where no treatment was applied, yielded a net profit of approximately 3,300 KHR/ARE. This amount served as the baseline, representing the typical economic return from rice farming under standard conditions without any additional interventions or enhancements.

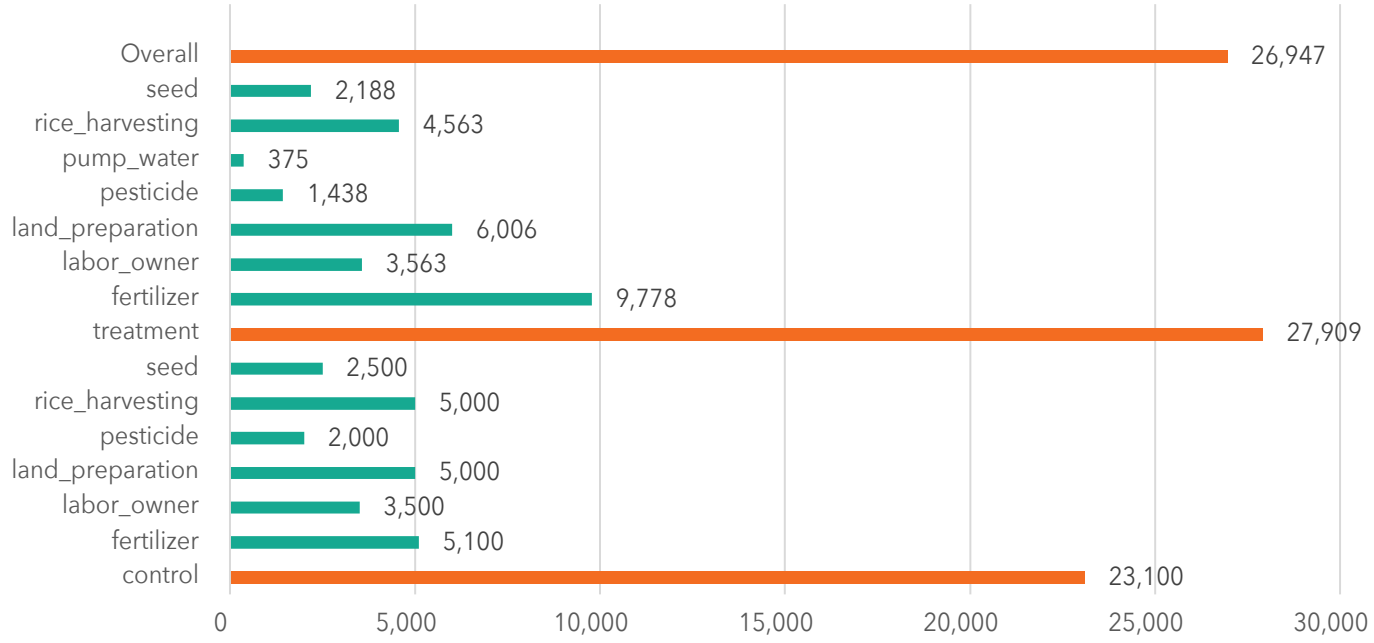
In contrast, the treatment sites exhibited a higher net profit, reaching around 12,980 KHR/ARE. This substantial increase in profitability indicates that the treatment applied to the rice farming process has a strong positive impact, potentially through factors such as improved crop yields, more efficient use of resources, or cost reductions. The dramatic difference between the control and treatment sites underscores the effectiveness of the treatment in enhancing the financial returns from rice farming.

Overall, this comparison highlights the potential economic benefits of adopting the treatment in rice production. With the treatment sites achieving nearly six times the net profit of the control sites, the data suggest that such interventions can play a crucial role in boosting the profitability and sustainability of rice farming. In addition, we found that the income of treatment farmers was also affected by the usage of organic fertilizers, both in previous experiments and in this one. To improve the accuracy of future experiments, the soil should be tested beforehand.

The economic analysis conducted in this experiment is based on a single cycle of rice cultivation. However, it is important to note that in real farming practices, some farmers who have ponds often cultivate rice for two or three cycles per year, utilizing water from their rice-field pond to sustain additional crops. In contrast, fish can only be harvested once per cycle. As a result, the economic benefits observed in this analysis may underrepresent the full potential of the treatment, as the cumulative gains from multiple rice cultivation cycles could enhance overall profitability for these farmers. Future analyses should consider the multiple cropping cycles for rice, particularly for farmers with ponds, to provide a more comprehensive understanding of the economic impact, while also considering the single-cycle nature of fish harvesting.

Figure 16 details the costs associated with rice farming under the two different treatments, measured in KHR/ARE per 100 square meters. The overall cost for the treatment sites was 27,909 KHR/ARE, which was slightly higher than the control sites' cost of 23,100 KHR/ARE. This difference is driven by specific expenses such land preparation and organic fertilizer, which were generally higher in the treatment sites. The treatment sites spent more on land preparation (6,006 KHR/ARE) and fertilizer (9,778 KHR/ARE) compared to the control (5,000 KHR/ARE for land preparation and 5,100 KHR/ARE for fertilizer). However, the control sites incurred higher costs for seed (2,500 KHR/ARE) and pesticide (2,000 KHR/ARE). Overall, the treatment involved higher costs, likely reflecting the investment in more improved farming practices aimed at boosting productivity, whereas the control represented more traditional, less costly methods.

Figure 16. Detailed listing of all costs for rice (KHR/ARE).



5. Discussion

The findings from this experiment highlight the potential of integrating climate-resilient practices in rice-field fisheries to enhance agricultural productivity and profitability. The experiment demonstrated that farmers with rice-field ponds can leverage these water resources not only to support multiple cycles of rice cultivation per year but also to sustain fish populations, contributing to both food security and income generation. This dual use of rice-field ponds underscores their importance in rural farming systems, particularly in regions prone to variable rainfall and water scarcity.

Previous studies by Vann Chanmunny (2015) in Pursat reported an average fish production of 29.75 kg per season from a 64 m² rice-field pond, resulting in an overall average of approximately 0.46 kg/m². In comparison, our study found lower yields, with treatment sites achieving an average of 0.16 kg/m² in Prey Veng and 0.14 kg/m² in Takeo. Although the average production per square meter in our study sites was still low compared to the yields from rice-field ponds in Pursat, where the fisheries system is better managed, our interventions were effective in improving fish yield at the individual pond level. However, it is important to note that in Prey Veng and Takeo, the interventions focused solely on improving individual ponds, without addressing the broader rice-field fisheries system. This limited scope of the intervention likely contributed to the lower overall production compared to regions where the whole system is better managed (Brook et al 2014, Kim et al 2019).

In addition, this production is lower than that of small-scale aquaculture, which yields approximately 0.35 kg/m² (Oliver, 2012). However, unlike small-scale aquaculture, rice-field pond production requires significantly less time and input costs. Notably, some farmers who practiced aquaculture in ponds nearby their rice fields discontinued these efforts after project completion. Instead, they began allowing wild fish to enter the ponds naturally and then harvested them during the dry season, reflecting a shift toward less intensive management.

The economic analysis revealed that overall rice production yields were approximately 10,500 KHR/ARE per cycle, while rice-field pond production yields were about 138,600. These figures suggest that rice-field ponds are more productive. However, it is important to note that the rice production data reflect only one cycle, whereas some farmers were able to cultivate two or three cycles by utilizing both rainfall and water stored in rice field ponds. Additionally, the cost of digging the ponds was not included in this calculation.

Moreover, many farmers were unwilling to enlarge their ponds, as doing so would have reduced the amount of land available for crop production. In some cases, farmers preferred to maintain the land for potential future uses, such as building a house or dividing the property among their children. In fact, some farmers opted to deepen their existing ponds rather than expand them during the dry season, indicating a preference for optimizing current resources rather than altering land use. Through the discussion, the 15 participants of the field day visits to the rice-field ponds expressed interest in adopting the activities to improve their pond.

The rice-field pond plays a crucial role in climate resilience by providing a reliable source of water during periods of reduced rainfall or no water availability. This allows farmers to maintain rice production and other agricultural activities even in challenging conditions. The ability to cultivate rice for two or three cycles per year, supported by water from these ponds, enhances the overall productivity and profitability of the farming system. This is particularly important as climate change continues to impact rainfall patterns, making the availability of water for agriculture.

The experiment also reveals synergies between fish and rice production. Although fish can only be harvested once per cycle, the ability to cultivate rice multiple times a year means that the overall economic benefits of the integrated system are likely higher than those observed in this single-cycle analysis. The increase in net profit observed in the treatment sites for both fish and rice highlights the value of adopting improved management practices, such as mechanized seeding, pond management, and the use of climate-resilient.

6. Conclusions

Farmers who integrate rice-field ponds into their agricultural practices often cultivate rice for two or three cycles per year, using the water from their ponds to sustain additional crops. These ponds play a critical role in enhancing climate resilience by providing a reliable source of water for rice cultivation and other uses during periods of reduced rainfall or drought. The increasing gains from these multiple cultivation cycles can boost overall profitability for farmers.

In the context of fish growth within these ponds for the study, walking catfish exhibited the highest average gains in both weight (34.66 g) and length (4.76 cm), making it the fastest-growing species. Snakehead also showed growth, with an average weight gain of 31.15 g and a length gain of 3.75 cm. Climbing perch had the lowest gains, with 23.13 g in weight and 2.09 cm in length. Despite growth within three months from the natural feed available in the ponds, the harvested fish were still relatively small, not reaching the ideal market weight of 300–1000 g per fish. Observations indicate that natural feed resources were nearly depleted, and additional feed would have been required to sustain further growth if the fish were not harvested soon.

The analysis of species composition reveals that snakehead, climbing perch, and walking catfish were the top-three species harvested across both the treatment and control ponds. Snakehead dominated the catch, comprising 55% of the harvest in the treatment ponds and 59% in the control ponds, making it the most prevalent species overall. Climbing perch was the second-most harvested species, particularly in the control ponds, while walking catfish was more prominent in the treatment ponds. These three species represent the majority of the fish harvested, with their dominance influenced by fish in the whole rice-field fisheries system.

The comprehensive analysis of fish and rice production across the different sites shows that targeted interventions led to increases in total production. Enhanced pond management practices, such as improvements to infrastructure, aquatic plant management, and habitat development, resulted in a substantial rise in net profits per area in both Prey Veng and Takeo. The production in the treatment ponds averaged 0.16 kg/m² in Prey Veng and 0.14 kg/m² in Takeo, demonstrating the effectiveness of these interventions. Prey Veng, with its favorable baseline conditions, consistently showed higher profitability, while Takeo, despite lower initial returns, experienced a more pronounced improvement, indicating that targeted interventions are particularly beneficial in less ideal environments. Similarly, the application of treatments in rice farming led to higher net profit per hectare compared to the control sites, highlighting the effectiveness of these interventions in enhancing rice production and overall economic sustainability. These results emphasize the importance of adopting targeted management practices and infrastructure improvements to maximize production and profitability, ultimately contributing to the sustainability and economic success of these agricultural practices.

Moreover, the patterns of fish utilization between the treatment and control ponds highlight the impact of different management practices. In the treatment ponds, 51% of the fish were sold, reflecting a market-driven approach, while 27% were given as gifts, and 22% were consumed or processed, showing a balanced utilization strategy. In contrast, the control ponds showed a slightly higher percentage of fish sold (56%), with fewer gifts (5%) and more consumption or processing (39%). This suggests that the increased production in the treatment ponds allowed for greater community sharing and slightly less reliance on personal consumption.

Finally, the participatory on-farm experiment underscores the effectiveness of integrating climate-resilient practices into rice-field fisheries. These practices enhance fish yield, income, and rice productivity compared to traditional methods, directly addressing climate change challenges while contributing to food security and farmer livelihoods. The involvement of farmers in this process not only increases the relevance and adoption of these innovative practices but also supports long-term agricultural sustainability. This experiment offers valuable insights for scaling these practices across the Asian Mega-Deltas, helping to secure food systems and livelihoods in the face of climate challenges.

7. Limitation and recommendations

The experiment was completed as planned, but several challenges were encountered. When analyzing the growth data for climbing perch, snakehead, and walking catfish, it is important to acknowledge these challenges during the harvesting process. One major issue was the regrowth of fins, which made it difficult to distinguish between stocked and wild fish. Additionally, some of the stocked fish could not be harvested because of accumulated mud in the pond. The mud hindered the collection of all the fish, affecting some results of the experiment.

This limitation might have impacted the accuracy of the growth data, as the inability to recover all the marked fish could have resulted in an incomplete representation of the actual growth and survival rates. Consequently, the growth measurements recorded might not fully reflect the performance of the entire stocked population, and this factor should be considered when interpreting the results. Based on nearly a year of experimentation, the following recommendations are essential to enhance the future experiments:

- Feed the fish after stocking. Although natural feed is produced during the wet season to sustain the fish through the dry season, it is challenging to provide enough feed when numerous wild fish return to the pond alongside the stocked fish. Currently, black soldier fly larvae are easy to grow or purchase from other producers. Given that the price of wet larvae is less than $1, using them as feed could be both cost-effective and beneficial for weight gain. Moreover the fish would reach the ideal market weight for sale, earnings farmers higher returns.
- To improve the reliability of future experiments, farmers should apply the organic fertilizer and seed at the same rate across all sites, and the soil should be tested before the trials. Standardizing these factors will reduce variability and allow for a clearer analysis of the treatment effects, ensuring more accurate and consistent results.
- After pumping, the pond fish should be collected twice: once on the same day as the pumping, and again the following day to ensure that most of the fish are harvested. During the current experiment, we were unable to retrieve all of the initially stocked marked fish.
- To make it easier to identify fish in future experiments, material chips or tags should be used to mark fish, rather than clipping fins. This method will allow for more accurate identification of the marked fish.

Rice-field ponds play a crucial role in enhancing fish production, particularly by providing a habitat for fish in challenging environments. During times of drought, these ponds serve as vital refuges for fish species that would otherwise survive in critical conditions. To fully realize the potential of rice-field ponds, the following recommendations are essential:

- The national government should actively promote the integration of rice-field ponds into a comprehensive community-based water management strategy. Encouraging the widespread adoption of these ponds will help create a more resilient agricultural system, reducing dependency on external water sources and increasing self-sufficiency. This approach will benefit not only individual farmers but also enhance overall community resilience in the face of climate change. However, current regulations that restrict farmers from digging ponds in rice fields should be reviewed and revised to support sustainable water management. By removing these legal barriers and promoting the responsible development of rice-field ponds, the government can foster broader rural development, ensuring that effective water resource management delivers benefits to entire communities.
- Local government staff should facilitate the process. In some areas, digging ponds requires permission from various provincial departments, including the Mines and Energy and Fisheries Administration Cantonment, even when the excavation occurs in private rice fields. These regulatory requirements can discourage farmers from creating ponds, potentially hindering their ability to manage water resources effectively during dry periods.
- Farmers should maintain approximately 10% of broodfish and then release the water back into the pond. This beneficial practice helps ensure a greater fish population for the next cycle, improving overall production and sustainability. By keeping a portion of the broodfish in the pond, natural reproduction and replenishment occur, which improves the health and productivity of the rice-field ecosystem. Additionally, establishing good connections between rice fields and ponds and creating fish habitats within the ponds further supports ecological balance and productivity.
- Enhance the overall productivity and sustainability of rice-field fisheries in Mekong Delta, it is essential to expand the scope of interventions beyond individual ricefield pond management to a holistic approach that encompasses the entire fisheries system. This can be achieved by strengthening the management of over 180 CFR (FiA 2022) in collaboration with the Fisheries Administration, would be benefiting more people in the Mekong Delta.

References

Brooks, A., Kim, M., Sieu, C., Sean, V., & Try, V. (2015). A characterization of community fish refuge typologies in rice field fisheries ecosystems.

Fisheries Administration. (2022). Annual fisheries statistics 2022, Cambodia.

Fisheries Administration. (2014). Cambodian fisheries at a glance. Fisheries Administration of Cambodia.

Freed, S., Kura, Y., Sean, V., Mith, S., Cohen, P. J., Kim, M., Thay, S., & Chhy, S. (2020). Rice field fisheries: Wild aquatic species diversity, food provision services, and contribution to inland fisheries. *Fisheries Research, 229*, 105615.

Joffre,O. *(2012) Aquaculture production in Cambodia.*.

Kim, M., Mam, K., Sean, V., Brooks, A., Thay, S., Hav, V., & Gregory, R. (2019). *A manual for community fish refuge–rice field fisheries system management in Cambodia*. Fisheries Administration and WorldFish Cambodia.

Ministry of Agriculture, Forestry, and Fisheries. (2022). *Annual report of agriculture, forestry, and fisheries 2021 and directions 2022*. MAFF.

Nuppun (2016). How important are the rice field fisheries? A follow-up survey around the Tonle Sap Lake. Study report for the Rice Field Fisheries Enhancement Project (RFFEP).

Vann Chanmunny. (2015). Determination of fish diversity, biomass, and survival rate of fish stocked in rice field refuge ponds during the dry season in Pursat Province. Master's thesis, Royal University of Phnom Penh.

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